CHAPTER 5 Work, energy, power

In common usage, the word 'work' means any physical or mental exertion. But in physics, work has a distinctly different meaning. Let us consider the following situations : (1) A student holds a heavy chair at arm's length for several minutes. (2) A student carries a bucket of water along a horizontal path while walking at constant velocity. (3) A student applying force against a wall. (4) A student studying whole day to prepare for examinations. It might surprise you to know that in all the above situations, no work is done according to the definition of work in physics., even though effort is required in all cases.

5.1 The concept of work

In physics, the word 'work' has a definite and precise meaning. Work is not done on an object unless the object is moved with the action of a force. The application of a force alone does not constitute work. For example, when a student holds the chair in his hand, he exerts a force to support the chair. But, work is not done on the chair as the chair does not move.

- Two important conditions that must be satisfied for work to be done are : (i) a force should act on an object (ii) the object must be displaced. If any one of the above conditions does not exist, work is not done. This is the concept of work that we use in science.
- Also, if force and displacement are perpendicular to each other, work is not done.

Mathematical definition of work

A constant force is applied in the direction of the displacement of an object : Let a constant force, F acts on an object. Let the object be displaced through a distance, s in the direction of the force (see fig.1(a)). Let W be the work done. Here, we define work to be equal to '**the product of the force and displacement**'.

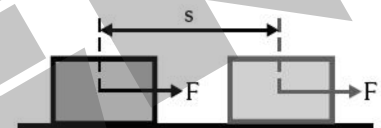


Fig.1(a) Work done by a constant force acting in the direction of displacement

Work done = force × displacement

$\boxed{W = F \times s}$

A constant force is applied at a certain angle with the direction of the displacement of an object : When the force on an object and the object's displacement are in different directions, the work done on the object is given by,

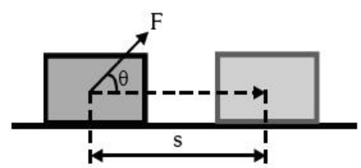


Fig.1(b) Work done by a constant force acting a an angle with the direction of displacement

$\boxed{W = F \times s \times \cos\theta}$

Where, the angle between the force and the direction of the displacement is θ (see fig.1(b)).

Here, we define work to be equal to '**the force multiplied by the displacement multiplied by the cosine of the angle between them**'.

■ Work is a scalar quantity, it has only magnitude and no direction.

Unit of work : S.I. unit : Joule 1 Joule = 1 newton × 1 metre or **1 J = 1 N m**

C.G.S. unit : Erg 1 erg = 1 dyne × 1 centimetre or **1 erg = 1 Dyne cm**

1 Joule = 10^7 ergs

Definition of 1 joule : 1 J is the amount of work done on an object when a force of 1 N displaces it by 1 m along the line of action of the force.

Some important points related to work

(1) If $\theta = 0°$, then $\cos 0° = 1$ and $W = F \times s$.

(2) If $\theta = 90°$, then, $W = 0$ because $\cos 90° = 0$. So, no work is done on a bucket being carried by a girl walking horizontally. The upward force exerted by the girl to support the bucket is perpendicular to the displacement of the bucket, which results in no work done on the bucket.

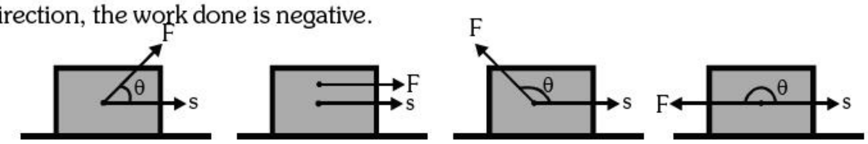
(3) If $\theta = 180°$, then $\cos 180° = -1$ and $W = -F \times s$.

Concept of negative and positive work

The work done by a force can be either positive or negative.

Whenever angle (θ) between the force and the displacement is acute, i.e., $0° < \theta < 90°$, the work done is positive. Also, when angle (θ) between the force and displacement is zero, i.e., force and displacement are in same direction, the work done is positive.

Whenever angle (θ) between the force and the displacement is obtuse, i.e., $90° < \theta < 180°$, the work done is negative. Also, when angle (θ) between the force and displacement is 180°, i.e., force and displacement are in opposite direction, the work done is negative.



θ is acute angle Work is positive (a) | θ is zero Work is positive (b) | θ is obtuse angle Work is negative (c) | θ is 180° Work is negative (d)

Fig.2 Concept of positive and negative work

- Area under the force (F) - displacement (s) graph gives the work done on an object or a system.

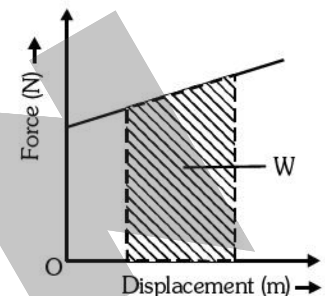


Fig.3 Area under force-displacement graph gives work done.

- An artificial satellite is moving around the Earth in a circular path under the influence of centripetal force provided by the gravitational force between them. Centripetal force (F) is always perpendicular to the displacement (s) of the particle moving along a circular path. That is, the angle (θ) between them is 90°.

  Work done, $W = F\,s\cos\theta = F\,s\cos 90° = 0$

  Thus, work done by this centripetal force is zero.

  - Work done by the centripetal force is always zero because it is always perpendicular to the displacement. For example, if an electron moves around a nucleus in a circular path due to centripetal force provided by the electric force between them, the work done by this force is zero.

5.2 Work done by applied force against gravity

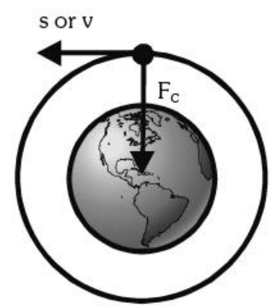


Fig.4 Work done by the centripetal force is zero

If an object is lifted up to a certain height (see fig.5), definitely, a work is done by the applied force. The applied force must be equal to the weight (= mg) of the object.

This work done is given by, $\mathbf{W = F \times s = mgh}$

Where, m = mass of object ; g = acceleration due to gravity ; h = height.

- Whenever a person holds an object in his hands or supports an object over his head, he is always applying a force in upward direction.
  - When a person lifts a body from the ground i.e., displaces it in upward direction, the work done by him is positive (see fig.6) as force and displacement are in same direction. When a person puts an object from a certain height to the ground i.e., displaces it in downward direction, the work done by him is negative (see fig.6) as force and displacement are in opposite direction.
  - When a person lifts a body from the ground i.e., displaces it in upward direction, the work done by force of gravity is negative (see fig.6) as force of gravity and displacement are in opposite direction. When a person puts an object from a certain height to the ground i.e., displaces it in downward direction, the work done by the force of gravity is positive (see fig.6) as force of gravity and displacement are in same direction.

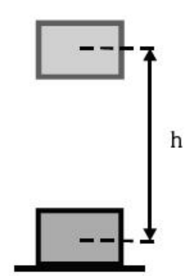


Fig.5 Work done against gravity

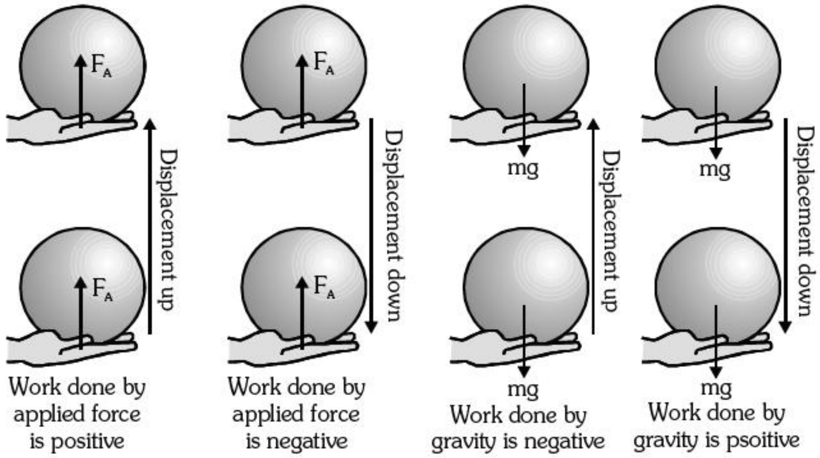


Fig.6 Work done by the applied force and gravity when an object is raised or lowered

- The work done against gravity depends on the difference in vertical heights of the initial and final positions of the object and not on the path along which the object is moved. This is because force of gravity is a conservative force. Fig.7 shows a case where a block is raised from position A to B by taking two different paths. Let the height AB = h. In both the situations the work done on the object is 'mgh'.

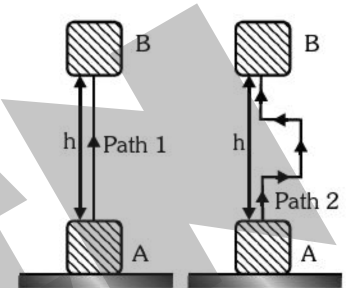


Fig.7 Work done against gravity depends only on initial position and final position

NUMERICAL CHALLENGE 5.1

1. A force of 6 N is applied on an object at an angle of 60° with the horizontal. Calculate the work done in moving the object by 2 m in the horizontal direction.

Solution

Given, force, F = 6 N ; angle between force and displacement, $\theta = 60°$; displacement, s = 2 m.

We know that work done, $W = F\, s \cos\theta = 6 \times 2 \cos 60° = 6 \times 2 \times (1/2) =$ **6 J**

2. A person lifts a sack of 5 kg potatoes from the ground floor to a height of 4 m to bring it to first floor. Calculate the work done.

Solution

Given, mass, m = 5 kg ; displacement, h = 4 m ; let us take, acceleration due to gravity, $g = 9.8\ m/s^2$

Since the potatoes are lifted, work is being done against gravity. Therefore, we can write,

Work done = mgh = $5 \times 9.8 \times 4 =$ **196 J**

3. A bag of grains of mass 2 kg is lifted through a height of 5 m. (a) How much work is done by the lift force ? (b) How much work is done by the force of gravity ?

Solution

Given, mass, m = 2 kg ; displacement, s = h = 5 m

(a) Here, work done by the lift force is positive as both lift force and the displacement are in same direction (upward direction).

Thus, work done by the lift force, $W = +\,mgh = +\,2 \times 9.8 \times 5 =$ **98 J**

(b) Here, work done by the force of gravity is negative as the force of gravity acts in downward direction while the displacement is in upward direction i.e., both are in opposite directions.

Thus, work done by the force of gravity, $W = -\,mgh = -\,2 \times 9.8 \times 5 =$ **– 98 J**

NUMERICAL CHALLENGE 5.2

1. Calculate the work done by applying a force of 20 N to a 0.4 kg box as it slides along a frictionless surface from rest to 10 m/s in 0.2 s.

Solution

Given, force, F = 20 N ; mass, m = 0.4 kg ; displacement, s = ? ; initial velocity, u = 0 ;

final velocity, v = 10 m/s ; time, t = 0.2 s ; Work done, W = ?

Now, displacement, $s = \left(\frac{v+u}{2}\right)t = \left(\frac{10+0}{2}\right) \times 0.2 = 1$ m

Work done, W = F × s = 20 × 1 = **20 J**

2. Calculate the work done on a cyclist if a braking force of 40 N (backward) slows the cyclist from 20 m/s to 15 m/s in 2.0 s.

Solution

Given, force, F = 40 N ; displacement, s = ? ; initial velocity, u = 20 m/s ; final velocity, v = 15 m/s ;

time, t = 2 s ; Work done, W = ?

Since, the displacement and force are in opposite direction, angle between them is 180° i.e., $\theta = 180°$.

Now, displacement, $s = \left(\frac{v+u}{2}\right)t = \left(\frac{15+20}{2}\right) \times 2 = 35$ m

$W = F s \cos\theta = 40 \times 35 \times \cos 180° = 40 \times 35 \times (-1) =$ **– 1400 J** $(\cos 180° = -1)$

3. Calculate the work done in graph shown in fig.8.

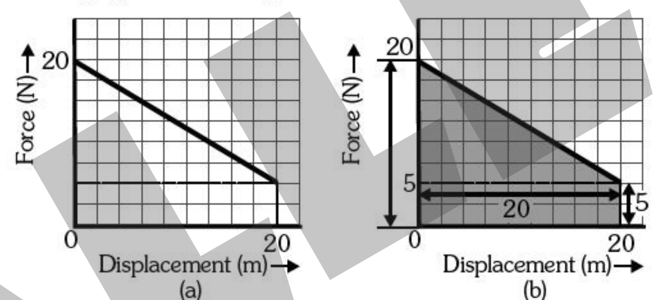


Fig.8 Numerical challenge 5.2

Solution

We know that area under the Force- displacement graph gives the total work done. Using fig.8(b), we can find the area under the given graph.

Work done, W = area of trapezium shown in fig.8(b)

$$= \frac{1}{2}(\text{Sum of the parallel sides}) \times (\text{distance between them}) = \frac{1}{2}(20+5) \times (20) = \mathbf{250\ J}$$

4. A truck pulls a 3000 kg car from rest with a horizontal force of 5000 N. The truck and car accelerate at 2.5 m/s² for 5.0 s to reach the speed of 45 km/h. How much work is done by the truck ?

Solution

Given, force, F = 5000 N ; displacement, s = ? ; acceleration, a = 2.5 m/s² ; initial velocity, u = 0 ;

final velocity, v = 45 km/h = (5/18) × 45 = 12.5 m/s ; Work done, W = ?

$v^2 - u^2 = 2as$

or $(12.5)^2 - (0)^2 = 2 \times 2.5 \times s$

or $s = \frac{12.5 \times 12.5}{2 \times 2.5} = 31.25$ m

Work done, $W = Fs\cos\theta = Fs\cos 0° = 5000 \times 31.25 = 156250$ J = **156.25 kJ**

5.3 Energy

Without light that comes to us from the Sun, life on Earth would not exist. With the light energy, plants can grow and the oceans and atmosphere can maintain temperature ranges that support life. Although energy is difficult to define comprehensively, a simple definition is that **energy is the capacity to do work**. Thus, when you think of energy, think of what work is involved.

■ An object that possesses energy can exert a force on another object. When this happens, energy is transferred from first object to the second object. The second object may move as it receives energy and therefore do some work. Thus, the first object had a capacity to do work. This implies that any object that possesses energy can do work.

Unit of energy :

S.I. unit : Since, energy is the capacity to do work, its unit is same as that of work, that is, Joule (J). 1 J is the energy required to do 1 joule of work. Sometimes a larger unit of energy called kilo joule (kJ) is used, 1 kJ = 1000 J.

C.G.S. unit : Erg $1\ J = 10^7$ ergs

Forms of energy

The world we live in provides energy in many different forms. The various forms include potential energy, kinetic energy, heat energy, chemical energy, electrical energy and light energy.

Mechanical energy

The capacity to do mechanical work is called mechanical energy. Mechanical energy can be of two types :
(1) Kinetic energy (2) Potential energy

■ The sum of the gravitational potential energy and the kinetic energy is called mechanical energy.

Kinetic energy

This is the energy a body has due to its movement. To give a body KE, work must be done on the body. The amount of work done will be equal to the increase in KE.

- Kinetic energy is the energy associated with an object in motion.
- Kinetic energy possessed by an object of mass m and moving with a uniform velocity v is

$$\boxed{E_k = \frac{1}{2}mv^2}$$

- For a given mass, kinetic energy $E_K \propto v^2$. That is, more the value of v, more will be the kinetic energy. Also, if we double the velocity, the kinetic energy becomes four times, if we triple the velocity, the kinetic energy becomes nine times, and so on.
- For a given velocity, $E_K \propto m$. That is, more the mass, more will be the kinetic energy of a body. If a car and a truck are moving with same velocity, the truck possesses more kinetic energy than that of car because the truck has more mass than that of the car.

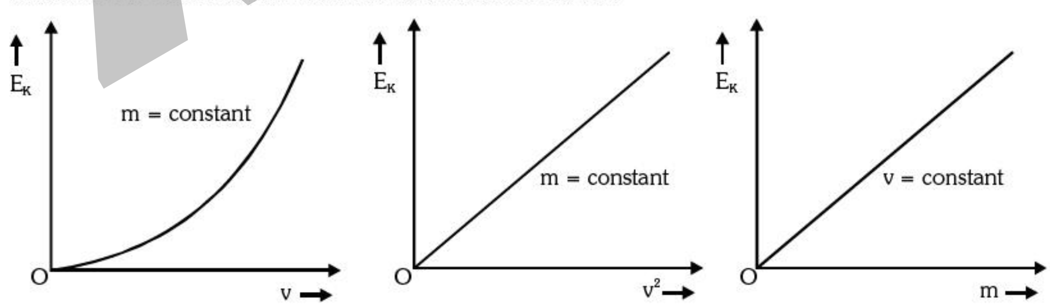


Fig.9 Graphs relating kinetic energy, velocity and mass.

• Relationship between momentum and kinetic energy

Momentum, $p = mv$ ----- (1)

Kinetic energy, $E_K = \frac{1}{2}mv^2 = \frac{1}{2}mv^2 \times \frac{m}{m} = \frac{1}{2}\frac{(mv)^2}{m}$ ----- (2)

From (1) & (2), we get, $\boxed{E_K = \frac{p^2}{2m}}$ Also, $\boxed{p = \sqrt{2mE_K}}$

For a given momentum, kinetic energy is inversely proportional to mass ($E_K \propto 1/m$). This means smaller the mass, more will be the kinetic energy and vice-versa. For a given kinetic energy, momentum is directly proportional to the square root of mass ($p \propto \sqrt{m}$). This means heavier body will have more momentum and vice-versa. For a given mass, momentum is directly proportional to the square root of kinetic energy ($p \propto \sqrt{E_K}$). This means more the kinetic energy, more will be the momentum and vice-versa. (see fig. 10)

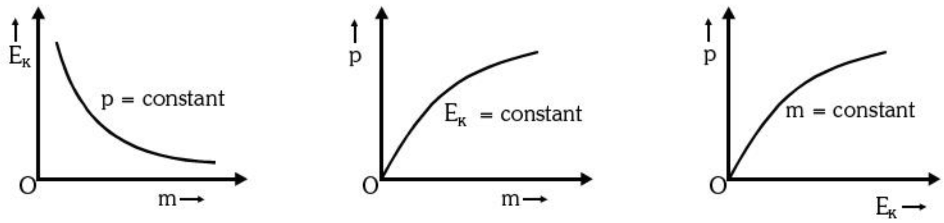


Fig.10 Graphs related to momentum, kinetic energy and mass.

Potential energy

The energy possessed by an object due to its position or configuration is called 'potential energy'.

- Potential energy is associated with an object that has the potential to move because of its position or configuration.

Gravitational potential energy

The energy associated with an object due to the object's position relative to a gravitational source is called gravitational potential energy.

- Gravitational potential energy is energy due to an object's position in a gravitational field. Imagine an egg falling off a table. As it falls, it gains kinetic energy. But, where does the egg's kinetic energy come from ? It comes from the gravitational potential energy that is associated with the egg's initial position on the table relative to the floor.

  We know that, the work done on the object against gravity is W = mgh. This work done is the energy gained by the object. This is the potential energy (E_p) of the object. That is,

  $$\boxed{E_p = W = mgh}$$

  The above formula actually represents, change in potential energy $\Delta PE = (U_f - U_i)$. Assuming initial potential energy (U_i) as zero and final potential energy (U_f) = E_p, we get, $\mathbf{E_p = mgh}$.

- If in a problem, several masses are involved at different vertical positions, then you can assume the potential energy of the mass at the lowest position as zero and you find the potential energies of other masses with respect to the mass at lowest position.

Elastic potential energy

Suppose a spring is placed on a tabletop and it is fixed at one end. Now, push a block on the spring, compressing the spring, and then release the block. The block slides across the tabletop. The kinetic energy of the block came from the stored energy in the compressed spring (see fig.11). This potential energy is called **elastic potential energy**.

■ Elastic potential energy is stored in any compressed or stretched object, such as a spring or the stretched strings of a tennis racket or guitar.

The length of a spring when no external forces are acting on it is called the **relaxed length** of the spring. When an external force compresses or stretches the spring, elastic potential energy is stored in the spring. The amount of energy depends on the distance the spring is compressed or stretched from its relaxed length.

The elastic potential energy stored in a spring is given by,

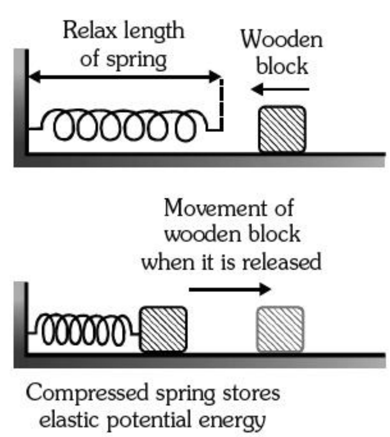


Fig.11 Elastic potential energy of a spring

$$\boxed{E_p = \frac{1}{2}Kx^2}$$

Where, K = spring constant or force constant and x = distance compressed or stretched from the relaxed position of a spring.

Some important points relate to work and energy

(1) Net work done on a particle or a system of particles is given by,

$$W_{net} = W_c + W_{nc} + W_{ext}$$

Where, W_c = work done by conservative forces ; W_{nc} = work done by the non conservative forces ; W_{ext} = work done by external or applied forces.

- Work done by conservative forces like elastic forces, gravitational forces is given by,

  $W_c = -$ change in potential energy $= -\Delta PE = -(U_f - U_i) = U_i - U_f$

  Where, U_f = final potential energy ; U_i = initial potential energy

- Work done by non conservative forces like frictional forces, air resistance, etc. is always negative as they are always opposite to displacement.

(2) Net work done by all the forces i.e., the work done by the unbalanced force is always equal to change in kinetic energy.

$W_{net} = \Delta KE = K_f - K_i$ or $\boxed{W_{net} = \frac{1}{2}mv^2 - \frac{1}{2}mu^2}$ This is called **work-energy theorem**.

or $W_c + W_{nc} + W_{ext} = K_f - K_i$

(3) **Work done by the spring :** Since elastic forces are conservative forces, the work done by the spring is given by,

$W = -\Delta PE = -(U_f - U_i) = U_i - U_f$ or $\boxed{W = \frac{1}{2}Kx_i^2 - \frac{1}{2}Kx_f^2}$

(4) If non conservative forces are absent, $W_{nc} = 0$. Then,

$W_c + W_{ext} = K_f - K_i$ or $U_i - U_f + W_{ext} = K_f - K_i$

or $\mathbf{W_{ext} = (K_f + U_f) - (K_i + U_i) = E_f - E_i}$

Where, E_f = final mechanical energy ; E_i = initial mechanical energy

(5) If non conservative forces are absent, $W_{nc} = 0$ and if no external forces are acting, $W_{ext} = 0$. Then,

$W_c = K_f - K_i$

or $U_i - U_f = K_f - K_i$

or $U_f + K_f = U_i + K_i$ or $\mathbf{E_f = E_i}$

Where, E_f = final mechanical energy ; E_i = initial mechanical energy

Thus, in the absence of non-conservative forces and external forces, total mechanical energy remains conserved or constant.

(6) If a body is lifted with certain acceleration to reach height h, then work done by the external force is given by,

$W_c + W_{nc} + W_{ext} = K_f - K_i$

or $W_c + (0) + W_{ext} = K_f - K_i$ $[W_{nc} = 0]$

or $(U_i - U_f) + W_{ext} = K_f - K_i$

or $(0 - U_f) + W_{ext} = K_f - K_i$ [Assuming, $U_i = 0$]

or $W_{ext} = K_f - K_i + U_f$ or $\boxed{W_{ext} = \left(\frac{1}{2}mv^2 - \frac{1}{2}mu^2\right) + mgh}$

NUMERICAL CHALLENGE 5.3

1. A 1400 kg car accelerates from 36 km/h to 54 km/h.

(a) How much work is done on the car ?

(b) If the car then brakes to a stop, how much work is done on it ?

Solution

(a) Given, mass of car, m = 1400 kg ; initial velocity, u = 36 km/h = 36 × (5/18) = 10 m/s ;
final velocity, v = 54 km/h = 54 × (5/18) = 15 m/s

According to work-energy theorem, work done, W = Change in kinetic energy

$$W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2 = \frac{1}{2}m(v^2 - u^2) = \frac{1}{2}\times 1400\times[(15)^2 - (10)^2] = \frac{1}{2}\times 1400\times[225-100]$$

or $W = \frac{1}{2}\times 1400\times 125$ = **87500 J = 8.75 ×10⁴ J**

(b) If the car is now stopped, then its final velocity becomes zero.

Now, initial velocity, u = 54 km/h = 15 m/s ; final velocity, v = 0

Work done, $W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2 = \frac{1}{2}m(v^2 - u^2) = \frac{1}{2}\times 1400\times[(0)^2 - (15)^2] = \frac{1}{2}\times 1400\times[0-225]$

or $W = \frac{1}{2}\times 1400\times[-225]$ = **$-$ 157500 J = $-$ 1.575 ×10^5 J**

2. A mass of 2 kg is attached to a light spring of force constant K =100 N/m. Calculate the work done by an external force in stretching the spring by 10 cm from its unstretched position.

Solution

Given, K = 100 N/m ; $x_i = 0$; x_f = 10 cm = 0.10 m

Work done by the external force = – work done by the spring = $-\left(\frac{1}{2}Kx_i^2 - \frac{1}{2}Kx_f^2\right) = \left(\frac{1}{2}Kx_f^2 - \frac{1}{2}Kx_i^2\right)$

or $W_{ext} = \frac{1}{2}K\left(x_f^2 - x_i^2\right) = \frac{1}{2}K\left(x_f^2 - x_i^2\right) = \frac{1}{2}\times 100\times[(0.1)^2 - (0)^2] = \frac{1}{2}\times 100\times 0.01$ = **0.5 J**

5.4 Conservation of energy

Energy appears in many forms, such as heat, motion, height, pressure, electricity, and chemical bonds between atoms.

Energy transformations

Energy can be converted from one form to another form in different systems, machines or devices. Systems change as energy flows from one part of the system to another. Parts of the system may speed up, slow down, get warmer or colder, etc. Each change transfers energy or transforms energy from one form to another. For example, friction transforms energy of motion to energy of heat. A bow and arrow transform potential energy in a stretched bow into energy of motion (i.e., kinetic energy) of an arrow.

Law of conservation of energy

Energy can never be created or destroyed, just converted from one form into another. This is called **the law of conservation of energy**.

- The law of conservation of energy is one of the most important laws in physics. It applies to all forms of energy. **Energy has to come from somewhere :** The law of conservation of energy tells us energy cannot be created from nothing. If energy increases somewhere, it must decrease somewhere else. The key to understanding how systems change is to trace the flow of energy. Once we know how energy flows and transforms, we have a good understanding of how a system works. For example, when we use energy to drive a car, that energy comes from chemical energy stored in petrol. As we use the energy, the amount left in the form of petrol decreases.

- When a body is dropped from a certain height under gravity then, in the absence of any non-conservative forces like air resistance, the total mechanical energy of the body remains constant.
- When a spring fixed at one end and attached with other end is stretched or compressed on a frictionless surface and then allowed to release, it oscillates about its equilibrium position. But its total mechanical energy remains constant.

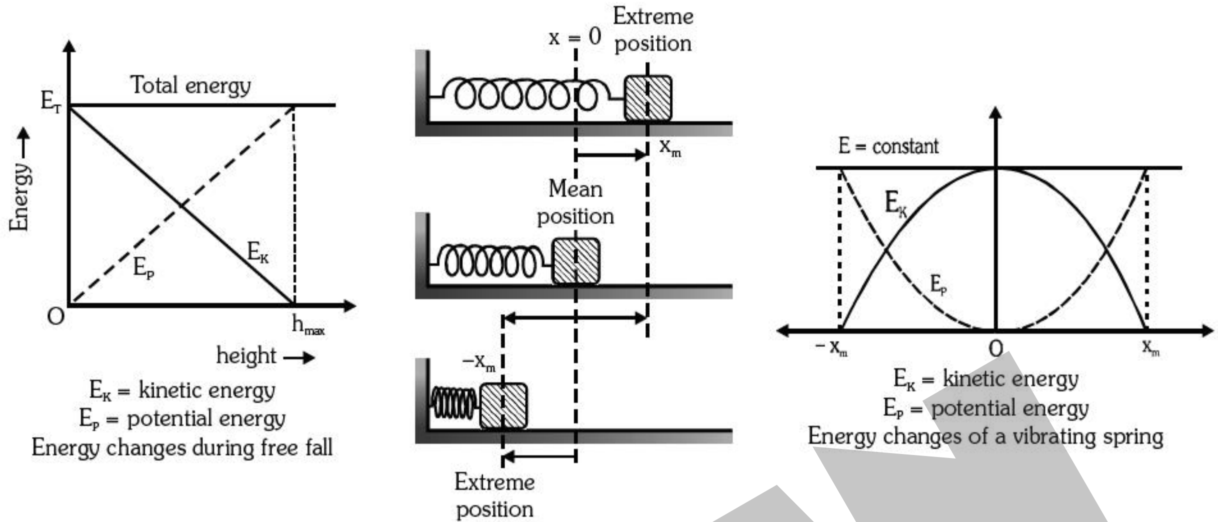


Fig.12 Conservation of energy during free fall and in a spring-mass system

NUMERICAL CHALLENGE 5.4

In fig.13, a frictionless metal block of mass 5.0 kg slides at a speed of 6.0 m/s into a fixed spring bumper with a spring constant of 720 N/m. What is the maximum compression of the block ?

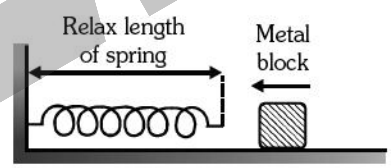


Fig.13 Numerical challenge 5.4

Solution

Given, mass, m = 5 kg ; speed, v = 6 m/s,

spring constant, K = 720 N/m

At maximum compression, the total kinetic energy will be converted to potential energy, i.e., $E_K = E_P$

or $\frac{1}{2}mv^2 = \frac{1}{2}Kx^2$ or $mv^2 = Kx^2$ or $x = v\sqrt{\frac{m}{K}} = 6\times\sqrt{\frac{5}{720}} = 6\times\sqrt{\frac{1}{144}} = \frac{6}{12}$ $= \mathbf{0.5\ m}$

5.5 Power

The engine in an old school bus could, over a long period of time, do as much work as jet engines do when a jet takes off. However, the school bus engine could not begin to do work fast enough to make a jet lift off. In this and many other applications, the rate at which work is done is more critical than the amount of work done.

- Power is the rate at which work is done. Power can also be defined as 'the rate at which energy is transferred'.

$$P = \frac{\text{Work done}}{\text{time taken}} = \frac{W}{t}$$

SI unit of power : Watt (W) 1 Watt = 1 joule/second

or **1 W = 1 J s^{-1}**

Definition of 1 watt : If 1 joule work is done per second by a device or a machine then the power of that device or machine is 1 watt.

- We know that, $P = \frac{\text{Work done}}{\text{time taken}} = \frac{W}{t} = \frac{F\times s}{t} = F\times\left(\frac{s}{t}\right) = F\times v$

NUMERICAL CHALLENGE 5.5

1. A car with a mass of 1.50×10^3 kg starts from rest and accelerates to a speed of 18.0 m/s in 12.0 s. Assume that the force of resistance remains constant at 400.0 N during this time. What is the power developed by the car's engine ?

Solution

Given, mass, $m = 1.50 \times 10^3$ kg ; initial velocity, $u = 0$; final velocity, $v = 18$ m/s ; time, $t = 12$ s ;

force of resistance, $F_r = 400$ N

Now, from first equation of motion,

$v = u + at$ or $18 = 0 + a(12)$ or $a = (18/12) = 1.5$ m/s^2

Net force, $F_n = ma = 1.50 \times 10^3 \times 1.5 = 2250$ N

Also, net force, F_n = Force developed by car's engine – Force of resistance

or $F_n = F_c - F_r$ or $F_c = F_n + F_r = 2250$ N + 400 N = 2650 N

Displacement, $s = \left(\frac{v+u}{2}\right)t = \left(\frac{18+0}{2}\right) \times 12 = 108$ m

Work done by car's engine, $W = F \times s = 2650 \times 108$ J

Power developed by car's engine, $P = \frac{W}{t} = \frac{2650 \times 108}{12} = 23850$ W = $\mathbf{2.385 \times 10^4}$ **W**

2. A man exerts a force of 200 N in pulling a cart at a constant speed of 16 m/s. Calculate the power spent by man.

Solution

Given, force, $F = 200$ N ; speed, $v = 16$ m/s

Power, $P = F \times v = 200 \times 16 =$ **3200 Watt**

3. Calculate the power of an engine required to lift 10^5 kg of coal per hour from a mine 360 m deep. ($g = 10$ m/s^2).

Solution

Given, mass, $m = 10^5$ kg ; $t = 1$ hr = 3600 s ; $h = 360$ m ; $g = 10$ m/s^2

Since, work is done against gravity, thus, work done, $W = mgh$

Power of the engine, $P = \frac{W}{t} = \frac{mgh}{t} = \frac{10^5 \times 10 \times 360}{3600} = \mathbf{10^5}$ **W**

Commercial unit of energy

The unit joule is an extremely small unit, it is inconvenient to express large quantities of energy in terms of joule. We use a bigger unit of energy called kilowatt hour (kWh). It is called commercial unit of energy.

Definition of 1 kWh : If a machine or a device of power 1 kW or 1000 W is used continuously for one hour, it will consume 1 kW h of energy. Thus, 1 kWh is the energy used in one hour at the rate of 1000 W (or 1 kW).

1 kW h = 1 kW × 1 h = 1000 W × 3600 s = 3600000 J or **1 kWh = 3.6 × 10⁶ J**.

EXERCISE

Multiple choice questions

1. A mass of 10 kg at point A on a table is moved to point B with an acceleration 10 m/s². If the line joining the A and B is horizontal, the work done on the mass is

(1) 10 kg × AB (2) 10 N × AB (3) 100 N × AB (4) 50 N × AB

2. A locomotive exerts a force of 7500 N and pulls a train by 1.5 km. The work done by the locomotive in mega joules is

(1) 12.25 MJ (2) 11.25 MJ (3) 10.75 MJ (4) 11.50 MJ

3. A horse does a work of 6250 J while applying a force of 250 N in pulling a tonga. The displacement produced in tonga is

(1) 12.5 m (2) 15 m (3) 25 m (4) 20 m

4. A person pulls a body on a horizontal surface by applying a force of 5.0 N at an angle of 30° with the horizontal. Find the work done by this force in displacing the body through 2.0 m.

(1) $5\sqrt{3}$ J (2) $6\sqrt{2}$ J (3) $7\sqrt{3}$ J (4) $4\sqrt{3}$ J

5. A body moves a distance of 5 m along a straight line under the action of a force of 10 N. If the work done is 25 J then the angle which the force makes with the direction of motion of the body is

(1) 0° (2) 30° (3) 60° (4) 90°

6. The work done by a pendulum after complete oscillation is

(1) zero

(2) equal to potential energy of the pendulum

(3) equal to kinetic energy of the pendulum

(4) equal to total energy of the pendulum

7. A body of mass m is moving along the circular track of radius r with a constant speed v. The force on the body is $\frac{mv^2}{r}$ and is directed towards the centre. The work done by this force in moving the body over half the circumference of the circle is

(1) $\frac{mv^2}{r}\times\pi r$ (2) $\frac{mv^2}{\pi r^2}$ (3) $\frac{\pi r^2}{mv^2}$ (4) zero

8. No work is done when an object moves

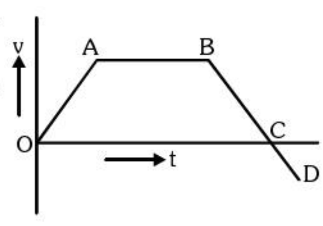
(1) along the direction of force (2) opposite to the direction of force

(3) at any angle to the direction of force (4) at 90° to the direction of force.

9. If the angle between force F and displacement s is 60°, then the work done is

(1) Fs (2) F / s (3) F × s / 2 (4) 2 Fs

10. A plot of velocity versus time is shown in figure. A single force acts on the body. The correct statement is



(1) In moving from C to D, work done by the force on the body is positive.

(2) In moving from B to C, work done by the force on the body is positive.

(3) In moving from A to B, the body does work on the system.

(4) In moving from O to A, work done on the body is negative.

11. A ball of mass 1 kg thrown upwards reaches a maximum height of 5.0 m. Calculate the work done by the force of gravity during this vertical displacement

(1) – 59 J (2) – 49 J (3) – 30 J (4) – 48 J

12. When work done by force of gravity is negative

(1) PE increases (2) KE increases (3) PE remains constant (4) PE decreases

13. An aeroplane flying at a height of 20,000 m at a speed of 300 kmh^{-1} has

(1) only potential energy (2) only kinetic energy

(3) both, potential and kinetic energy (4) none of the above

14. Energy possessed by a body on account of position or configuration is called

(1) kinetic energy (2) potential energy

(3) mechanical energy (4) magnetic energy.

15. A stone rolls down an inclined plane. Midway during the motion, the stone has

(1) only kinetic energy (2) only potential energy

(3) both kinetic and potential energy (4) neither potential nor kinetic energy.

16. The kinetic energy acquired by a body of mass m after travelling a fixed distance from rest under the action of a constant force is

(1) Directly proportional to mass m

(2) Inversely proportional to mass m

(3) Inversely proportional to mass $m^{1/2}$

(4) Independent of mass m

17. A uniform force of 4N acts on a body of mass 40 kg for a distance of 2.0 m. The kinetic energy acquired by the body is

(1) $4 \times 2 \times 2$ J (2) $4 \times 4 \times 2 \times 10^8$ erg

(3) 4×2 J (4) $4 \times 4 \times 2$ erg

18. A car is moving with a speed of 100 kmh^{-1}. If the mass of the car is 950 kg then its kinetic energy is

(1) 0.367 MJ (2) 3.67 J (3) 3.67 MJ (4) 3.67 J

19. If the speed of a vehicle increases by 2 m/s, its kinetic energy is doubled, then original speed of the vehicle is

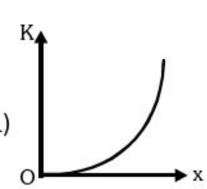
(1) $\left(\sqrt{2}+1\right)$ m/s (2) $2\left(\sqrt{2}-1\right)$ m/s

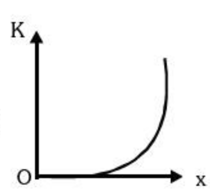
(3) $2\left(\sqrt{2}+1\right)$ m/s (4) $\sqrt{2}\left(\sqrt{2}+1\right)$ m/s

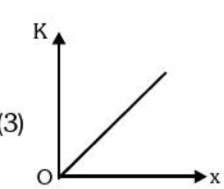
20. A running man has half the kinetic energy that a boy of half his mass has. The man speeds up by 1 m/sec and then has the same kinetic energy as the boy. What were the original speeds of man and boy respectively?

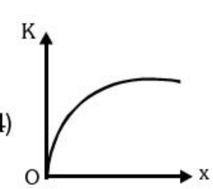
(1) 2.4, 4.8 m/sec (2) 2.4, 3.4 m/sec (3) 3.4, 4.8 m/sec (4) 3.4, 6.8 m/sec

21. A body moves from rest with a constant acceleration. Which one of the following graphs represents the variation of its kinetic energy K with the distance travelled x?

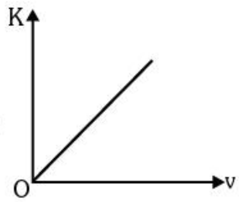
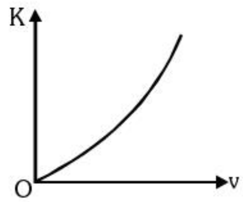
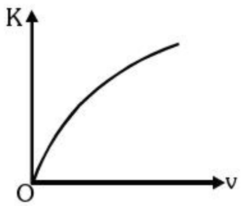
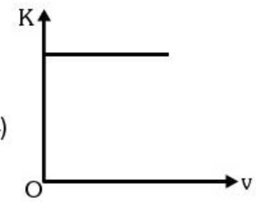
(1) 

(2) 

(3) 

(4) 

22. A graph was plotted between kinetic energy (K) and velocity (v) of the body. Which of the following represents correct graphical relation?

(1) 
(2) 
(3) 
(4) 

23. A block of mass M slides down the surface of a bowl of radius R from its rim to its bottom. What will be the kinetic energy of the block at the bottom?

(1) MgR (2) 2MgR (3) $Mg\frac{R}{2}$ (4) $Mg\frac{R}{4}$

24. The momentum of a body is doubled. What is the percentage increase in kinetic energy?

(1) 500 % (2) 300 % (3) 200 % (4) 600 %

25. The K.E. of a body of mass 2 kg and momentum of 3 Ns is

(1) 1 J (2) 2 J (3) 3 J (4) 2.25 J

26. A solid wooden block resting on a frictionless surface is hit by a bullet. The bullet gets embedded in block. During this process,

(1) Only kinetic energy is conserved.

(2) Only momentum is conserved.

(3) Both momentum and kinetic energy are conserved.

(4) Neither momentum nor kinetic energy is conserved.

27. The momentum of a body is numerically equal to the kinetic energy of the body. What is the velocity of the body?

(1) $\frac{1}{\sqrt{2}}$ units (2) 2 units (3) $\frac{1}{\sqrt{3}}$ units (4) $\sqrt{3}$ units

28. At a given time the momentum of a body of mass 5 kg is 10 $kgms^{-1}$. Now a force of 0.2 N acts on the body in the direction of motion for 10 seconds. The increase in kinetic energy is

(1) 2.2 J (2) 3.3 J (3) 4.4 J (4) 5.5 J

29. If the momentum of a body increases by 20%, the percentage increase in its kinetic energy will be

(1) 36 (2) 40 (3) 44 (4) 300

30. A bomb of mass 9 kg explodes into two pieces of mass 3 kg and 6 kg. The velocity of 3 kg mass is 16 m/s. The kinetic energy of 6 kg mass will be

(1) 96 J (2) 192 J (3) 384 J (4) 768 J

31. The kinetic energy of the body is increased by 300%. The percentage increase in momentum of the body will be

(1) 300 (2) 150 (3) 100 (4) 50

32. A bullet of mass 100 gm is fired with a velocity of 10 m/s from a gun of mass 1 kg. The ratio of kinetic energy of bullet to that of gun is

(1) 10:10 (2) 10 : 1 (3) 100:10 (4) 1:100

33. When the speed of a particle is doubled, the ratio of its kinetic energy to its momentum

(1) remains the same (2) gets doubled (3) becomes half (4) becomes four times

34. Kinetic energies of two bodies of 1 kg and 4 kg are same. The ratio of their momentum is

(1) 1 : 16 (2) 1 : 2 (3) $\sqrt{2}$: 1 (4) 4 : 1

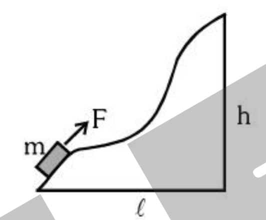
35. A body of mass m_1 moving with a velocity 10 ms^{-1} collides with another body at rest of mass m_2. After collision the velocities of the two bodies are 2 ms^{-1} and 5 ms^{-1} respectively along the direction of motion of m_1. The ratio m_1 / m_2 is

(1) 5/12 (2) 5/8 (3) 8/5 (4) 12/5

36. An object of mass 1 kg is raised through a height 'h'. Its potential energy is increased by 1 J. Find the height 'h'.

(1) 0.102 m (2) 0.105 m (3) 0.130 m (4)0.110 m

37. A body of mass m was slowly pulled up the hill by a force F which at each point was directed along the tangent of the trajectory. All surfaces are smooth. Find the work performed by this force.



(1) $mg\ell$ (2) $-mg\ell$ (3) mgh (4) zero

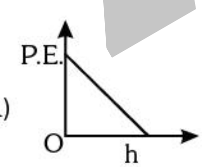
38. An object of mass 40 kg (g = 10 ms^{-2}) is raised to a height of 8 m above the ground. The gain in potential energy by the object is

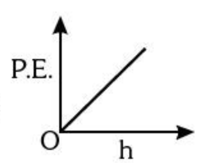
(1) 200 J (2) 3200 J (3) 1500 J (4) 1000 J

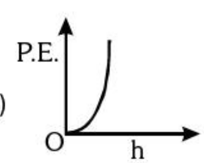
39. A block of mass 1 kg slides down on an inclined plane of inclination 30°. Find the work done by the weight of the block as it slides through 50 cm.

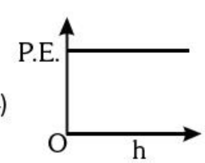
(1) 3.45 J (2) 5.30 J (3) 2.45 J (4) 3.50 J

40. If a graph between P.E. of the body in relation to the height through which it falls freely is plotted, it may be noted that the total energy remains the same. Which of the following graphs shows this relation correctly?

(1) 

(2) 

(3) 

(4) 

41. A block of 20 kg mass is pulled up a slope by applying a force acting parallel to the slope. If the slope makes an angle of 30° with the horizontal, calculate the work done in pulling the load up a distance of 3.0 m. What is the increase in potential energy of the block? Assume the force of friction is zero. (Take g = 10 N/kg)

(1) 300 J, 600 J (2) 600 J, 300 J

(3) 300 J, 300 J (4) 600 J, 600 J

42. Potential energy of a person is minimum when

(1) person is standing (2) person is sitting in the chair

(3) person is sitting on the ground (4) person is lying on the ground

43. **Statement-I :** A spring has potential energy, both when it is compressed or stretched.

Statement-II : In compressing or stretching, work is done on the spring against the restoring force.

(1) Both statements-I and II are true, statement-II is correct explanation for statement-I.

(2) Both statements-I and II are true, statement-II is not the correct explanation for statement-I.

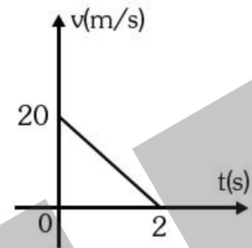
(3) Statement-I is true and statement-II is false.

(4) Statement-I is false and statement-II is true.

44. A long spring is stretched by 2 cm and its potential energy is U. If the spring is stretched by 10 cm, the potential energy stored in it will be

(1) $\frac{U}{5}$ (2) $\frac{U}{25}$ (3) 25 U (4) 5 U

45. Velocity-time graph of a particle of mass 2 kg moving in a straight line is as shown in figure. Work done by all the forces on the particle is



(1) 400 J (2) –400 J (3) –200 J (4) 200 J

46. Work done in time t on a body of mass m which is accelerated from rest to a speed v in time t_1, as a function of time t is given by

(1) $\left(\frac{1}{2}\right)m\left(\frac{v}{t_1}\right)t^2$ (2) $m\left(\frac{v}{t_1}\right)t^2$ (3) $\left(\frac{1}{2}\right)\left(\frac{mv}{t_1}\right)^2 t^2$ (4) $\left(\frac{1}{2}\right)m\left(\frac{v^2}{t_1^2}\right)t^2$

47. A body of mass 20 kg, slows down from 5 ms^{-1} to 2 ms^{-1} by a retarding force. The work done by the force is

(1) –50 J (2) –200 J (3) –300 J (4) –210 J

48. An object of mass 'm' is moving with a constant velocity 'v'. The work done on the object to bring it to rest is

(1) $-mv^2$ (2) $-\frac{1}{2}mv^2$ (3) mv (4) $\frac{1}{2}mv^2$

49. A car of mass 1500 kg is moving with a velocity of 60 kmh^{-1}. The work done by its brakes to bring it to rest is

(1) –208.33 kJ (2) –198.52 kJ (3) –112.42 kJ (4) –212.52 kJ

50. A lorry and a car with the same kinetic energy are brought to rest by the application of brakes which provide equal retarding forces. Which of them will come to rest in a shorter distance?

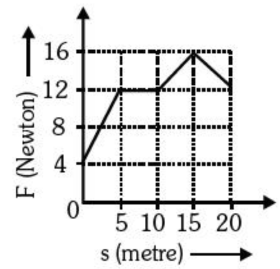
(1) Lorry

(2) Car

(3) Both will stop at the same distance

(4) Cannot be determined

51. Figure shows the frictional force versus displacement for a particle in motion. The loss of kinetic energy (work done against friction) in travelling over s = 0 to s = 20 m will be



(1) 80 J (2) 160 J (3) 240 J (4) 24 J

52. A mass m falls freely from rest. The linear momentum after it has fallen through a height h is
(g = acceleration due to gravity)

(1) $\sqrt{mgh}$ (2) $m\sqrt{2gh}$ (3) $m\sqrt{gh}$ (4) zero

53. In a spring gun having spring constant 100 N/m, a small ball of mass 0.1 kg is put in its barrel by compressing the spring through 0.05 m as shown in fig. Find the velocity of the ball when the spring is released.

(1) $\sqrt{2}$ m/s (2) $\sqrt{2.5}$ m/s (3) $\sqrt{3}$ m/s (4) $\sqrt{3.5}$ m/s

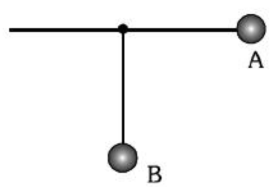
54. A 1 kg mass falls from a height of 10 m into a sand box. What is the speed of the mass just before hitting the sand box? If it travels a distance of 2 cm into the sand before coming to rest, what is the average retarding force?

(1) 12 m/sec and 3600 N (2) 14 m/sec and 4900 N
(3) 16 m/sec and 6400 N (4) 18 m/sec and 8100 N

55. A body of mass 2 kg is thrown up vertically with a kinetic energy of 490 J. If the acceleration due to gravity is 9.8 ms^{-2}, the height at which the kinetic energy of the body becomes half of the original value is

(1) 50 m (2) 25 m (3) 12.5 m (4) 10 m

56. A pendulum of length 2 m is left at A. When it reaches B, it loses 10% of its total energy due to air resistance. The velocity at B is

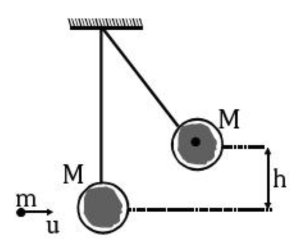


(1) 6 m/s (2) 1 m/s (3) 2 m/s (4) 8 m/s

57. A bullet of mass m, moving with velocity 'u' strikes a suspended wooden block of mass M, and gets embedded into it as shown in figure. If the block rises to a height h, the initial velocity will be given by

(1) $\sqrt{2gh}$ (2) $\left(\frac{M+m}{m}\right)\sqrt{2gh}$

(3) $\left(\frac{m}{M+m}\right)\sqrt{2gh}$ (4) $\left(\frac{M+m}{M-m}\right)\sqrt{2gh}$



58. If a body is raised through height 'h' on the surface of earth and the energy spent is E, then for the same amount of energy the body on the surface of moon will rise through the height of

(1) 2h (2) 6h (3) 4h (4) 12h

59. A body of mass 2 kg is projected vertically upwards with a speed of 3 m/s. The maximum gravitational potential energy of the body is

(1) 18 J (2) 4.5 J (3) 9 J (4) 2.25 J

60. A body is thrown upwards from a point A. It reaches up to the highest point B and returns, its

(1) Kinetic energy at A = kinetic energy at B

(2) Potential energy at A = potential energy at B

(3) Potential energy at B = kinetic energy at B

(4) Potential energy at B = kinetic energy at A

61. For a body falling freely under gravity, its kinetic energy

(1) Remains constant (2) Goes on increasing (3) Goes on decreasing (4) Is zero

62. A ball released from certain height loses 50% of its K.E. on striking the ground. It will attain a height again

(1) One fourth the initial (2) Half the initial (3) Three fourth the initial (4) None of these

63. A ball falling from a height of 5 m rebounds to 1.8 m height. Then the ratio of velocities of ball after and before rebound is

(1) 4/5 (2) 1/5 (3) 2/5 (4) 3/5

64. An elevator is designed to lift a load of 1000 kg through 6 floors of a building averaging 3·5 m per floor in 6 sec. Power of the elevator, neglecting other losses, will be

(1) $3{\cdot}43 \times 10^4$ watt (2) $4{\cdot}33 \times 10^4$ watt (3) $2{\cdot}21 \times 10^4$ watt (4) $5{\cdot}65 \times 10^4$ watt

65. A one kilowatt motor pumps out water from a well 10 meters deep. Calculate the quantity of water pumped out per second.

(1) 10.204 kg (2) 15.302 kg (3) 11.201 kg (4) 16.204 kg

66. A vehicle is moving on a straight horizontal road at a constant velocity of 10 m/s. The engine needs to spend 4 kJ of energy per second. The force on the vehicle is

(1) 0.2 kN (2) 0.4 kN (3) 0.6 kN (4) 1 N

67. An engine develops 10 KW of power. How much time will it take to lift a mass of 200 kg to a height of 40 m? (Given $g = 10\ m/s^2$)

(1) 4 s (2) 5 s (3) 8 s (4) 10 s

68. A weight lifter of power 1960 watt lifts a load of mass M from the ground to a height of 2m in 3 seconds. M is

(1) 100 kg (2) 200 kg (3) 300 kg (4) 400 kg

69. A horse pulls a wagon with a force of 360 N at an angle of 60° with the horizontal towards East at a speed of 10 kmh^{-1}. The power of the horse is

(1) 1000 W (2) 2000 W (3) 500 W (4) 750 W

70. A water pump driven by petrol rises water at a rate of 0.5 $m^3\,min^{-1}$ from a depth of 30 m. If the pump is 70% efficient, what power is developed by the engine?

(1) 1750 W (2) 2450 W (3) 3500 W (4) 7000 W

71. A person A does 500 J work in 10 minutes and another person B does 600 J of work in 20 minutes. Let the power delivered by A and B be P_1 and P_2 respectively, then

(1) $P_1 = P_2$ (2) $P_1 > P_2$ (3) $P_1 < P_2$ (4) P_1 and P_2 are undefined

72. The heart does 1.5 J of work in each heart beat. How many times per minute does it beat if its power is 2 W?

(1) 80 (2) 75 (3) 82 (4) 77

73. A man A of mass 80 kg runs up a staircase in 12 seconds. Another man B of mass 60 kg runs up the same staircase in 11 seconds. The ratio of powers of A and B is

(1) 11 : 12 (2) 11 : 19 (3) 12 : 11 (4) None of these

74. A body is moved along a straight line by a machine delivering constant power. The distance moved by the body in time t is proportional to

(1) $t^{1/2}$ (2) $t^{3/4}$ (3) $t^{3/2}$ (4) t^2

75. An electric motor creates a tension of 4500 N in hoisting a cable and reels it at a rate of 2 m/s. The power of the motor is

(1) 25 KW (2) 9 KW (3) 225 KW (4) 90 KW

76. A pump is required to lift 1000 kg of water per minute from a well 12 m deep and eject it with a speed of 20 m s^{-1}. What must be the power output of the pump?

(1) 2 kW (2) 4.72 kW (3) 5.33 kW (4) 6.21 kW

77. A machine gun fires 240 bullets per minute with a velocity 80 m s^{-1}. If the mass of each bullet is 0.04 kg, calculate the power of the gun.

(1) 2.13 kW (2) 512 W (3) 521 W (4) 746 W

78. An electric heater is rated 1500 W. The energy used by it in 10 hours is

(1) 5 kWh (2) 10 kWh (3) 15 kWh (4) 20 kWh

79. The energy consumed (in kWh) by four devices of 500 W each in 10 hours is

(1) 4 kWh (2) 5 kWh (3) 10 kWh (4) 20 kWh

80. In an explosion a body breaks up into two pieces of unequal masses. In this

(1) Both parts will have numerically equal momentum.

(2) Lighter part will have more momentum.

(3) Heavier part will have more momentum.

(4) Both parts will have equal kinetic energy.

ANSWERS

Que.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Ans.	3	2	3	1	3	1	4	4	3	1	2	1	3	2	3	4	3	1	3	1
Que.	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
Ans.	3	2	1	2	4	2	2	3	3	2	3	2	2	2	2	1	3	2	3	2
Que.	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**
Ans.	3	4	1	3	2	4	4	2	1	3	3	2	2	2	3	1	2	2	3	4
Que.	**61**	**62**	**63**	**64**	**65**	**66**	**67**	**68**	**69**	**70**	**71**	**72**	**73**	**74**	**75**	**76**	**77**	**78**	**79**	**80**
Ans.	2	2	4	1	1	2	3	3	3	3	2	1	4	3	2	3	2	3	4	1